



# CHARGED LEPTON FLAVOR AND LEPTON NUMBER VIOLATION AT LHCb



The 26th International Workshop on  
Weak Interactions and Neutrinos  
(WIN2017)

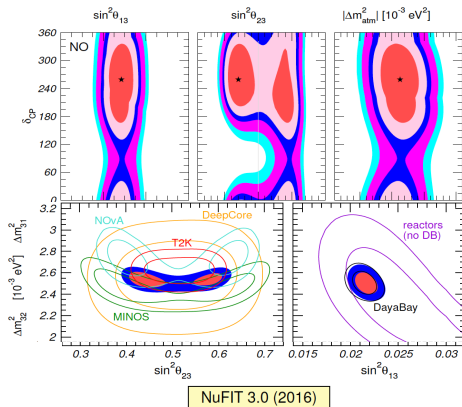
University of California Irvine  
June 19-24, 2017



**B. Adeva, on behalf of the  
LHCb collaboration**

## ORIGIN OF FERMION MASSES

### NEUTRINOS

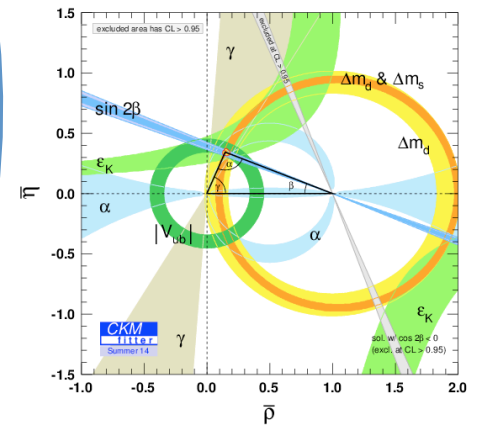


- Lepton universality
- Lepton flavor violation
- Flavor anomalies
- CP violation



- Oscillations
- Exotic CC and NC
- Majorana neutrinos

### QUARKS



## ORIGIN OF BARYON ASYMMETRY

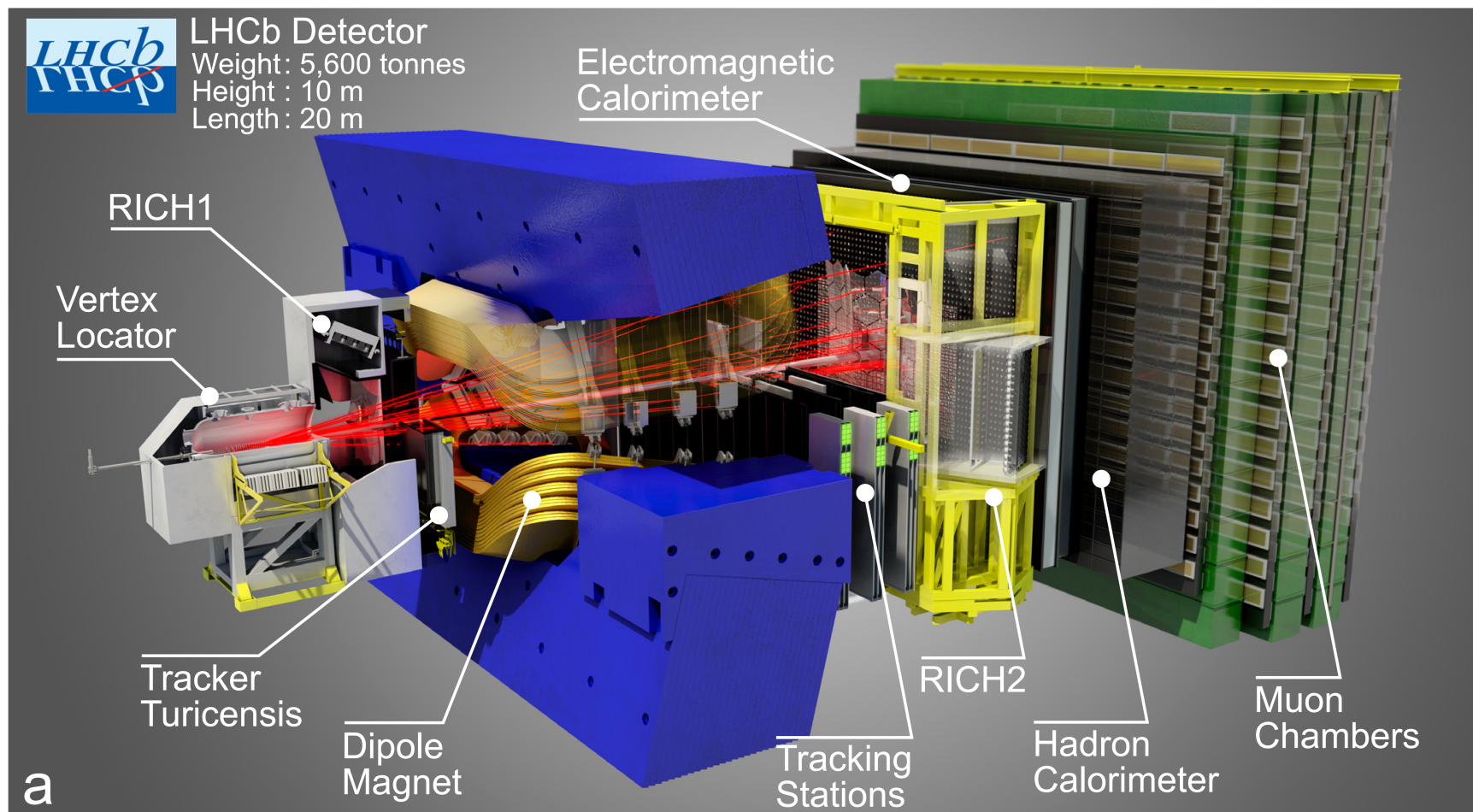
$$n_B / s = ( 8.676 \pm 0.054 ) \times 10^{-11} \quad \text{Planck 2015}$$

# OUTLINE OF TALK

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- ① The LHCb collider experiment
- ② Searches for GeV-scale sterile Majorana neutrinos
- ③ Recent lepton flavor violation (LFV) results in  $c$  and  $\tau$  decays
- ④ LFV versus lepton non universality (LNU) in  $b$ -decays
- ⑤ Lepton number violation (LNV) in low mass RPV SUSY

# THE LHCb APPARATUS



proper time :  $\Delta\tau \simeq 45\text{fs}$     impact parameter :  $\sigma_{\text{IP}} \simeq 35\text{ }\mu\text{m}$      $\Delta p/p \simeq (5 - 7) \times 10^{-3}$

The LHCb detector at the LHC, JINST 3 (2008) S08005, Int. J. Mod. Phys. A30 (2015) 1530022.

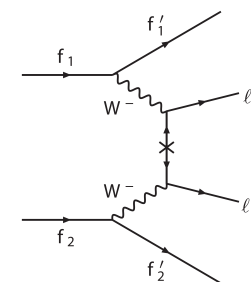
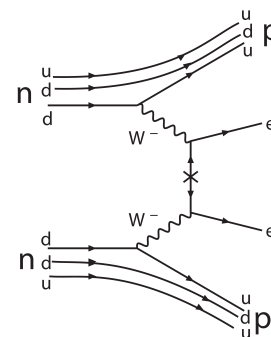
- RH neutrinos with Majorana masses in the GeV range can simultaneously explain the observed neutrino oscillations and the baryon asymmetry of the universe

M. Drewes, S. Eijima, arXiv: 1606.06221 (2017)

- Scenarios have been proposed where three or more GeV-scale sterile neutrinos participate in leptogenesis, even if there is no other physics beyond the SM

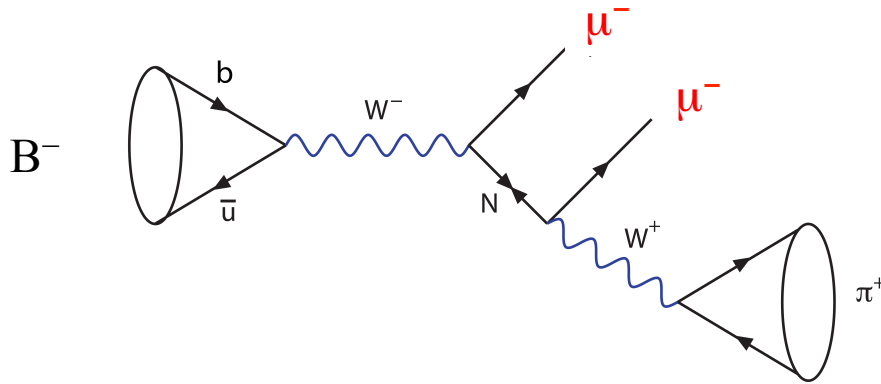
L. Canetti, M. Drewes, B. Garbrecht, arXiv: 1404.7114 (2015)

- Experimentally the GeV range is interesting because the RH neutrinos can be searched for in meson decays, either at LHCb or at B-factories (Belle II). Proposals for future fixed target experiments also exist, such as NA62, SHiP, or DUNE



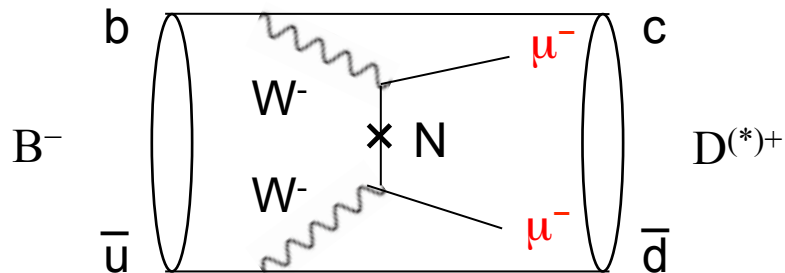
# MAJORANA NEUTRINOS IN B-DECAYS

- Coupling to an ON-SHELL 4<sup>th</sup> neutrino generation N:



Best option:  $B^- \rightarrow \mu^- N(\mu^- \pi^+)$   
 Resonant production,  
 mass analysis possible

- Additional modes with OFF-SHELL neutrinos N:

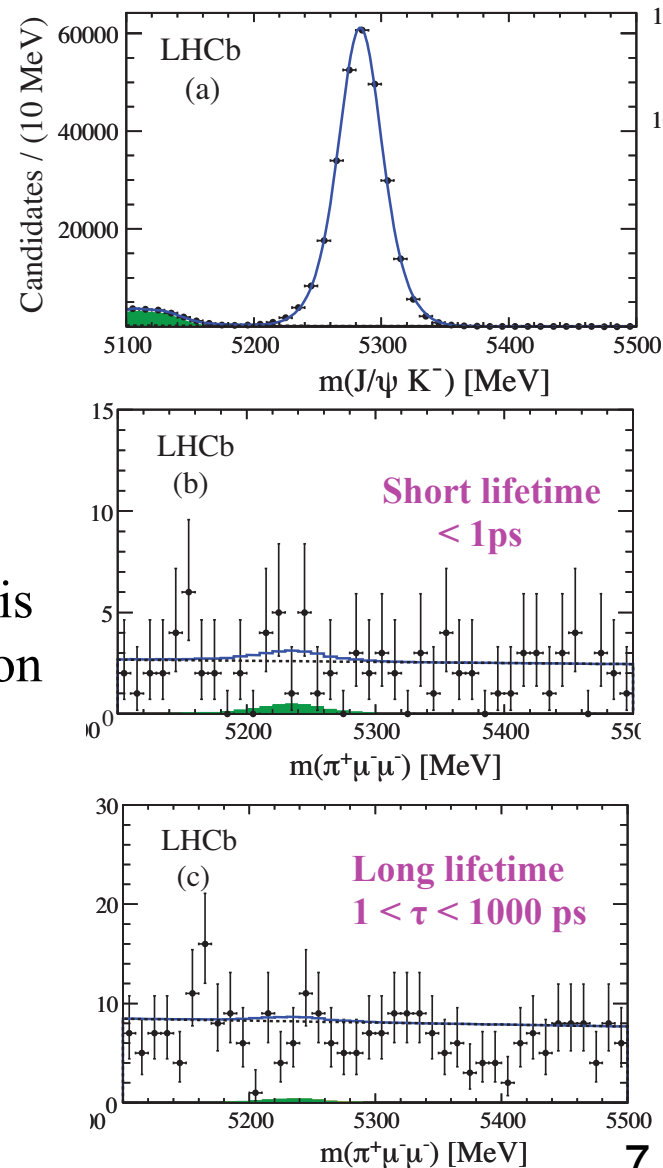


Charmed decays:  $B^- \rightarrow \mu^- \mu^- D^{(*)+}$   
*Entirely similar to neutrinoless  $2\beta$ -decay*  
 Virtual production, unspecific to mass

# $B^- \rightarrow \pi^+ \mu^- \mu^-$ AS A PROBE FOR $\nu_M$ SEARCH

- Very high integrated  $\mathcal{L}$  collected at pp collisions with  $\sqrt{s} = 8$  TeV ( $2 \text{ fb}^{-1}$ ) and  $\sqrt{s} = 7$  TeV ( $1 \text{ fb}^{-1}$ ), producing  $\geq 10^{12}$   $b\bar{b}$  pairs / year
- Excellent mass resolution, and precise secondary vertex location, achieved by 60 cm deep forward vertex detector (VELO), allows simultaneous analysis of the neutrino mass *and lifetime* spectrum, in a region  $1 < \tau < 1000$  ps
- A powerful normalization channel available to calibrate the detector performance:  $B^- \rightarrow J/\psi (\mu^+ \mu^-) K^-$

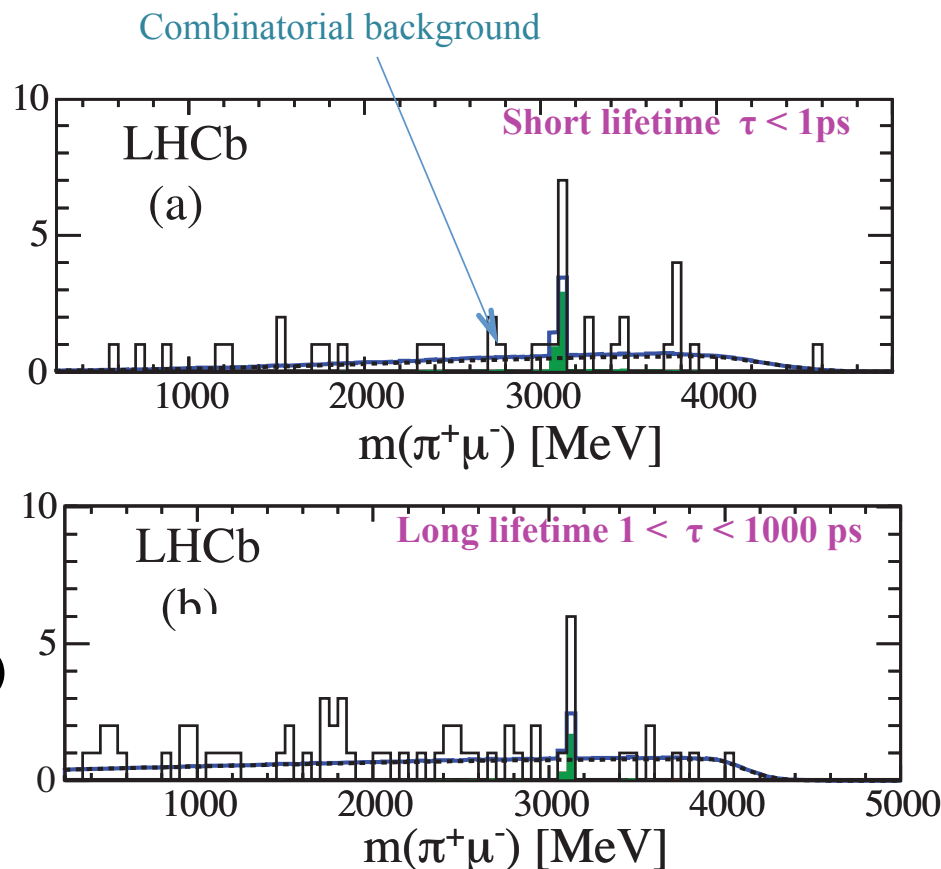
PRL **112** (2014),131802 [arXiv:1401.5361]



# RESULTS NEUTRINO MASS SPECTRUM

PRL **112** (2014),131802 [arXiv:1401.5361]

- Like-sign leptons and the requirement that the summed 3 charged particle momenta point to the PV perform large reduction of the background
- 19 evts ( $17.8 \pm 3.2$  bkg) are found in the B mass signal range, for short lifetime, and 60 evts ( $54.5 \pm 5.4$  bkg) for long lifetime, with average 95% CL limit:  
 $\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 4.0 \times 10^{-9} \quad (\tau_N \leq 1\text{ps})$
- Limits are improved by searching for a neutrino mass signal in 5 MeV steps within  $\pm 3\sigma$  of mass resolution



**peaking background at 3100 MeV from misid  $B^- \rightarrow J/\psi K^-$**

PRL **112** (2014),131802 [arXiv:1401.5361]

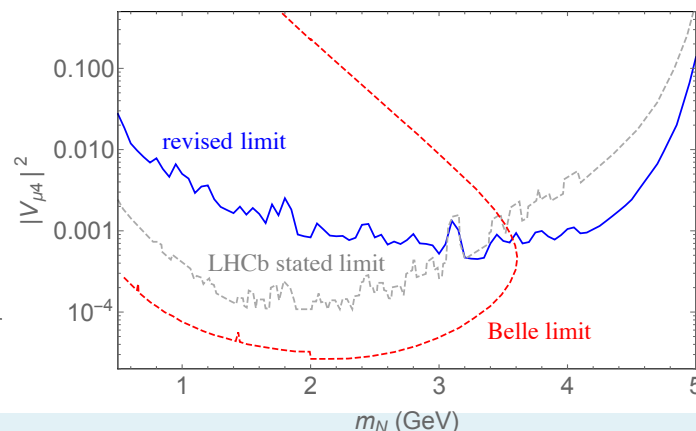
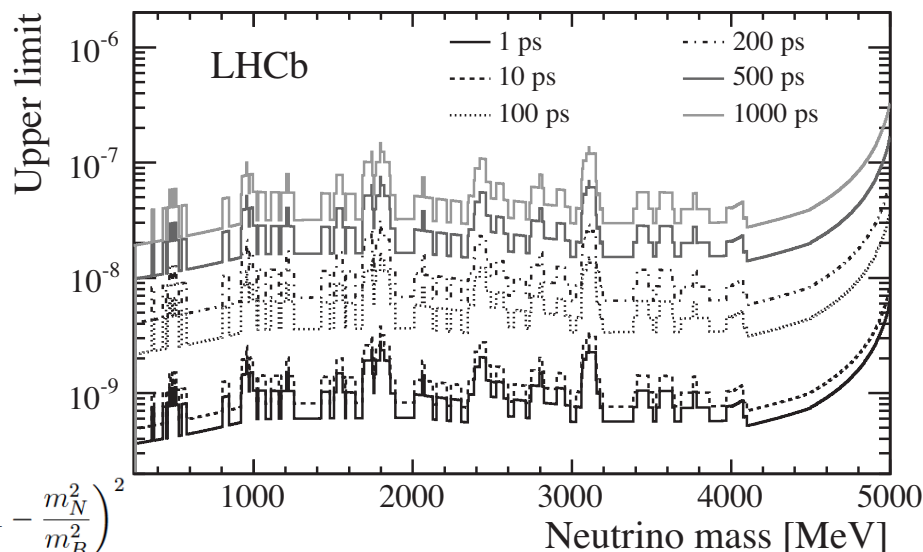
- Two-dimensional model-independent upper limits as function of  $m_N$  and lifetime  $\tau_N$
- Different efficiencies are computed at each lifetime step
- Model dependent 95% CL limits on the coupling of a 4<sup>th</sup> generation Majorana neutrino to muons  $|V_{\mu 4}|$ , for each value of  $m_N$ , can be extracted from

$$\mathcal{B}(B^- \rightarrow \mu^- N) \mathcal{B}(N \rightarrow \pi^+ \mu^-) = \tau_B \tau_N \frac{G_F^4 f_B^2 f_\pi^2 m_B m_N^5}{128 \pi^2 \hbar} |V_{\mu 4}|^4 |V_{ub} V_{ud}|^2 \left(1 - \frac{m_N^2}{m_B^2}\right)^2$$

Atre et al., JHEP **05** (2009) 030; see recent reappraisal by B. Shuve, M. E. Peskin, PRD **94** 113007 (2017) with improved theory. Belle limits are also indicated D. Liventsev et al. PRD **87** 071102 (2013) and erratum

- Ongoing updates from LHCb Run2 (Run3) extending to  $B \rightarrow D^{(*)} + 1N$  and  $B \rightarrow X + 1N$  final states, already used by Belle

Upper limits on  $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^- \mu^+)$  as function of neutrino lifetime (95% CL)



# SUMMARY LHCb RESULTS ON $B^- \rightarrow \mu^- N$

- A summary of other LHCb Majorana neutrino searches for (on-shell)  $B^- \rightarrow \mu^- N(\mu^- \pi^+)$  and (off-shell)  $B^- \rightarrow \mu^- \mu^- D^{(*)+}$ , for short-lived modes:

MODE	$\mathcal{B}_{UL}$ 95 % CL
$B^\pm \rightarrow K^\mp \mu^\pm \mu^\pm$	$5.4 \times 10^{-8}$
$B^\pm \rightarrow D^\mp \mu^\pm \mu^\pm$	$6.9 \times 10^{-7}$
$B^\pm \rightarrow D^{*\mp} \mu^\pm \mu^\pm$	$2.4 \times 10^{-6}$
$B^\pm \rightarrow \pi^\mp \mu^\pm \mu^\pm$	$4.0 \times 10^{-9}$
$B^\pm \rightarrow D_s^\mp \mu^\pm \mu^\pm$	$5.8 \times 10^{-7}$
$B^\pm \rightarrow D^0 \pi^\mp \mu^\pm \mu^\pm$	$1.5 \times 10^{-6}$

The LHCb collaboration,  
 Phys. Rev. Lett. **112** (2014),131802  
[\[arXiv:1401.5361\]](#)  
 Phys. Rev. Lett. **108** (2012),101601  
[\[arXiv:1110.0730\]](#)  
 Phys. Rev. **D85** (2012),112004  
[\[arXiv:1201.5600\]](#)

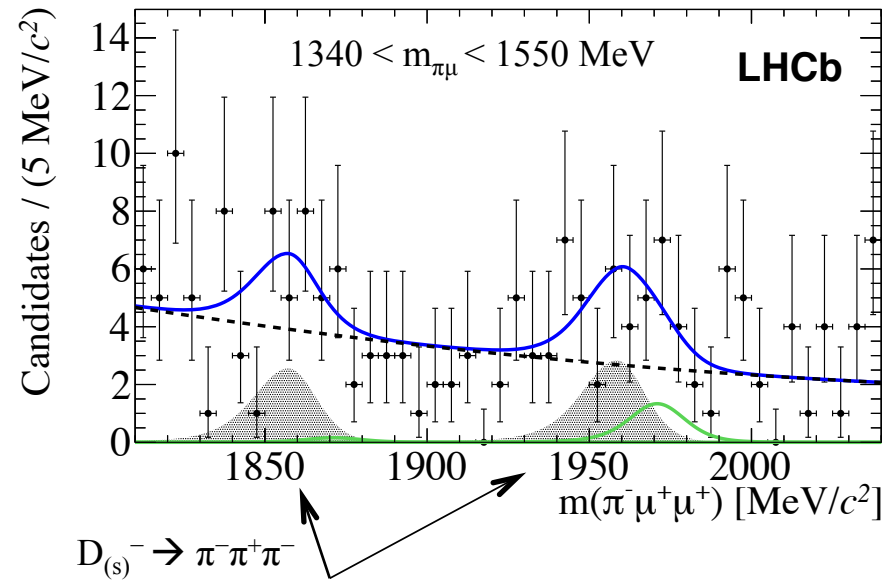
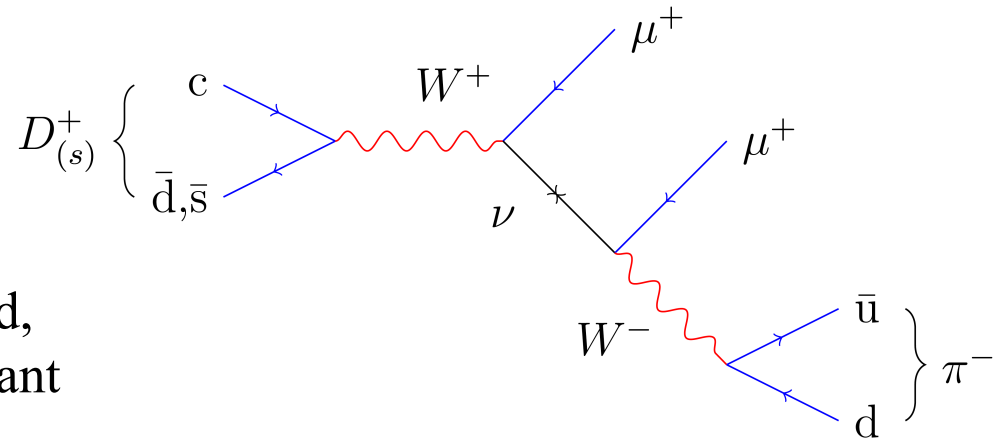
- These are world's best limits to date in their mass range
- In most cases updates have not yet been performed to the full luminosity acquired by LHCb in Run1. Improvements scale as  $\sqrt{\mathcal{L}}$

# NEUTRINOS FROM CHARM $D_{(s)}^- \rightarrow \mu^- N$

- Similarly as  $B^- \rightarrow \pi^+ \mu^- \mu^-$ , Majorana neutrinos can be searched for in the region  $250 < m_{\pi\mu} < 2000$  MeV from charm decays  $D_{(s)}^- \rightarrow \pi^+ \mu^- \mu^-$
- Upper limits on the  $\mathcal{B}$  's were obtained, in 4 bins of the mass  $m_{\pi\mu}$ . No significant excess of candidates was seen, using  $D_{(s)}^- \rightarrow \pi^+ \phi(\mu^+ \mu^-)$  as normalization.
- Important peaking background comes from misID  $D_{(s)}^- \rightarrow \pi^- \pi^+ \pi^-$  which is accurately determined

MODE	$\mathcal{B}_{UL}$ 95 % CL
$D^\pm \rightarrow \pi^\mp \mu^\pm \mu^\pm$	$2.5 \times 10^{-8}$
$D_s^\pm \rightarrow \pi^\mp \mu^\pm \mu^\pm$	$1.4 \times 10^{-7}$

Phys. Lett. **B724** (2013),203 [arXiv:1304.6365]



(only 1 fb<sup>-1</sup>)

- Upgrades of existing projects for  $B^- \rightarrow \mu^- N$  include LHCb (Run3), with possible use of  $W \rightarrow \mu N$  and  $Z^0$  decays, and Belle II.

Particular attention has been devoted to the decays of  $B_c$  meson:  $B_c^- \rightarrow \mu^- N$  and  $B_c^- \rightarrow \mu^- N$  with  $N \rightarrow \mu^- \pi^+$ , that will enable sensitivity  $|V_{\mu N}|^2 \sim O(10^{-5})$  at the LHC Run3

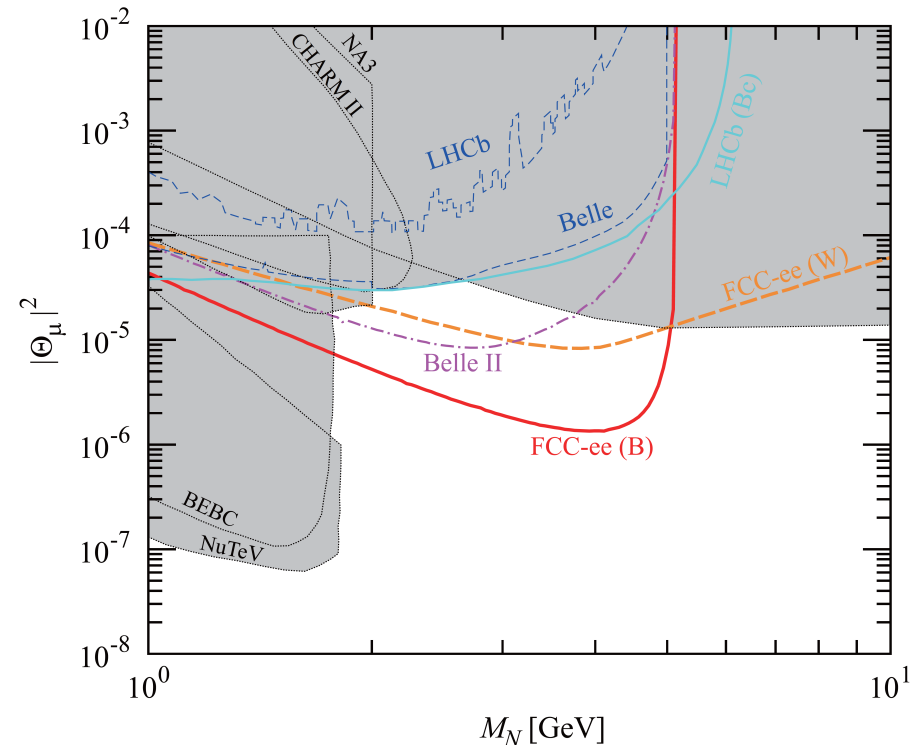
D. Milanés, Quintero, Vera,  
Phys. Rev. **D93** (2016), 094026.

- A future  $e^+e^-$  circular collider (FCC-ee) at the Z-pole may provide sensitivity down to  $10^{-6}$  from  $Z \rightarrow b\bar{b}$ , with a 2m detector

A. Blondel et al. , arXiv:1411.5230

- With FCC-ee at Z-pole,  $Z \rightarrow \nu N$  decays can provide even stronger limits, when detached vertices are used (down to  $10^{-10}$  for  $m_N \leq 10$  GeV)

T. Asaka and H. Ishida, arXiv:1609.06113 .



- Lepton flavor violation (LFV) from  $\nu$ -oscillations predict totally negligible rate to  $D^0 \rightarrow e^+ \mu^-$ . However, physics scenarios beyond the SM predict ample variation of possible rates :

SUSY RPV  $O(10^{-6})$  ; Multiple Higgs doublets  $< 7 \times 10^{-10}$  ; Extra fermions  $O(10^{-14})$

- Because  $c \rightarrow u e^+ \mu^-$  processes are related, current restrictions on  $D_s^- \rightarrow K^- e^+ \mu^-$  and  $D^- \rightarrow \pi^- e^+ \mu^-$  leave room for  $\mathcal{B}(D^0 \rightarrow e^+ \mu^-)$  as high as  $10^{-7}$

F. Tahir, A. Mir, S. Mahmood, Ch. Phys. C38 No. 12 (2014) 123101.

R. Wang et al., Int. J. Mod. Phys. A29 No. 29 (2014) 1450169.

- Current limit comes from Belle  $\mathcal{B}(D^0 \rightarrow e^+ \mu^-) < 2.6 \times 10^{-7}$  (90% CL), an improved limit  $O(10^{-7})$  could provide tighter constraints on coupling constants of RPV SUSY models, while a limit below  $4 \times 10^{-8}$  would also constrain the parameter space in some LEPTOQUARK MODELS

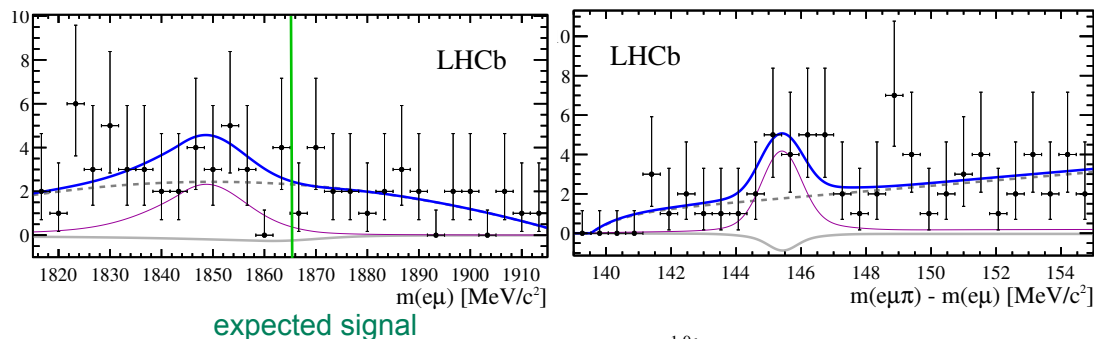
S. de Boer and G. Hiller, arXiv: 1510.00311.

Belle collaboration, M. Petric et al., Phys. Rev. D81 (2010) 091102, arXiv: 1003.2345

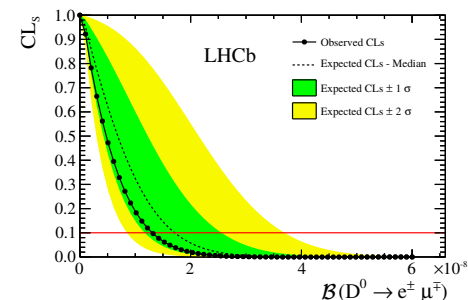
# LHCb RESULTS ON $D^0 \rightarrow e^+ \mu^-$

PLB 754 (2016), 167 [arXiv: 1512.00322]

- MisID from  $D^0 \rightarrow \pi^+ \pi^-$  decays is the dominant source of background. However mass peak is shifted by about 15 MeV below the signal mass, with misID probability  $(1.8 \pm 0.4) \times 10^{-8}$  (8 TeV data)



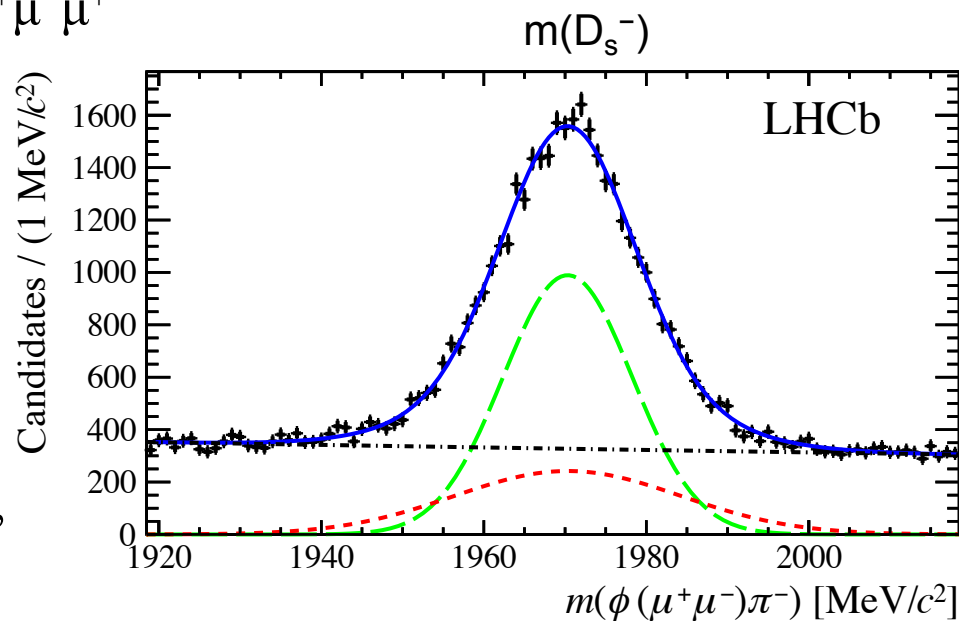
- No evidence is seen for any  $D^0 \rightarrow e^+ \mu^-$  signal. The fits return a total  $-7 \pm 15$  signal decays



- Upper limit is set  $\mathcal{B}(D^0 \rightarrow e^+ \mu^-) < 1.3 \times 10^{-8}$  90% CL ( $< 1.6 \times 10^{-8}$  95% CL) with excellent correspondance between expected and observed CL values
- An order of magnitude lower than previous limit, it will help to further constrain products of couplings of supersymmetric models with R-parity violation. It also constrains the parameter space in some leptoquark scenarios

# LEPTON FLAVOR VIOLATION IN $\tau^+ \rightarrow \mu^+ \mu^- \mu^+$

- In models of new physics with LFV,  $\tau$ -lepton is often enhanced. LHCb has examined the forbidden decay  $\tau^+ \rightarrow \mu^+ \mu^- \mu^+$
- $\tau$  yields are extremely high at the LHC, being entirely produced from b- and c-decays ( $\sim 85 \mu\text{b}$  are implied by LHCb measurements)
- The *displaced vertex* is seen at LHCb, with  $D_s^- \rightarrow \phi(\mu^+ \mu^-) \pi^-$  as an excellent calibration and normalization channel for this search
- Events are classified in 5 categories according to their source: directly from b, or from  $D_s^- / D^-$  initiated in turn from either b- or c-decays



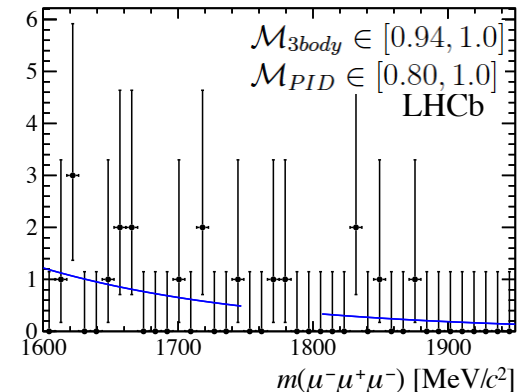
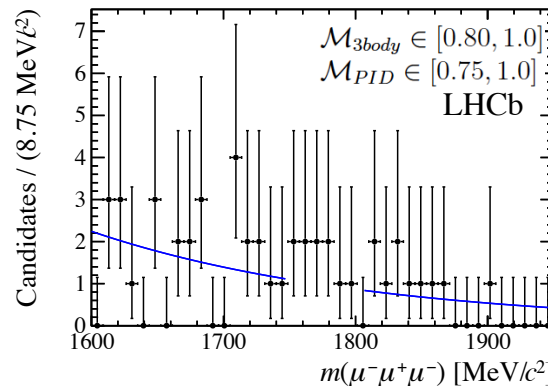
*mass PDF calibration used to search for  $m(\mu^+ \mu^- \mu^+)$  in  $\pm 20 \text{ MeV}$  of  $\tau$  mass*

JHEP 02 (2015) 121 [arXiv:1409.8548]

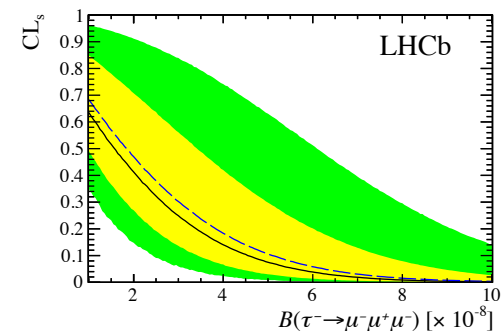
# $\tau^- \rightarrow \mu^+ \mu^- \mu^-$ ANALYSIS AND RESULTS

- Three classifiers  $\mathcal{M}_{\text{mass}}$ ,  $\mathcal{M}_{3\text{body}}$ ,  $\mathcal{M}_{\text{PID}}$  are defined to build a *blended* BDT discriminator
- Backgrounds from undetected particles in decays  $K_L^0$ ,  $\gamma$ ,  $\nu$  's ... are fitted at the signal sidebands

JHEP 02 (2015) 121.



- No significant excess is observed:  
 $\mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 4.6 \text{ (5.6)} \times 10^{-8}$  90% (95%) CL
- In combination with results from B factories, it puts constraints on a broad class of BSM physics



- Recent results have been reported by the LHCb experiment on possible lepton flavor non universality:

$$R_H \equiv \frac{\int \frac{d\Gamma(B \rightarrow H \mu^+ \mu^-)}{dq^2} dq^2}{\int \frac{d\Gamma(B \rightarrow H e^+ e^-)}{dq^2} dq^2} \quad R_{K^{*0}} = \begin{cases} 0.66_{-0.07}^{+0.11} (\text{stat}) \pm 0.03 (\text{syst}) & 0.045 < q^2 < 1.1 \text{ GeV}^2/c^4 \\ 0.69_{-0.07}^{+0.11} (\text{stat}) \pm 0.05 (\text{syst}) & 1.1 < q^2 < 6.0 \text{ GeV}^2/c^4 \end{cases}$$

$$R_K = 0.745_{-0.074}^{+0.090} (\text{stat}) \pm 0.036 (\text{syst}) \quad 1.0 < q^2 < 6.0 \text{ GeV}^2/c^4$$

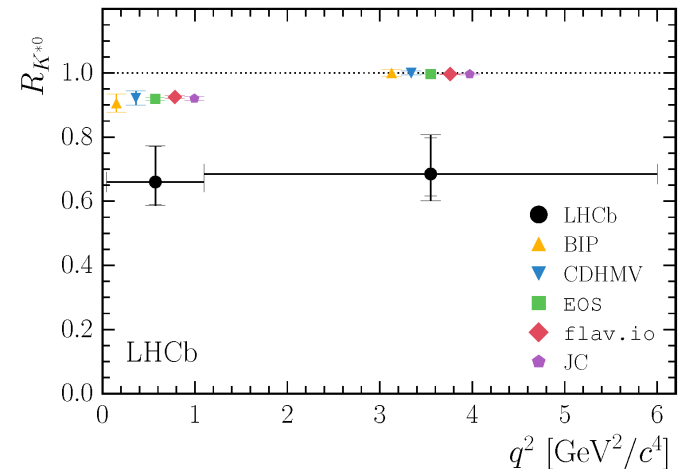
which are at variance with their SM predictions.

[arXiv:1705.05802 \(2017\)](#) and [PRL 113 \(2014\), 151601](#)

see also [A. Romero, CERN Seminar, June 6<sup>th</sup> 2017,](#)

[LHCb-PAPER-2017-017](#) (in prep.) for a recent  $R_{D^*}$  measurement on  $\tau$ -lepton

- Together with LHCb results on  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$  angular analysis [JHEP 02 \(2016\), 104](#), these findings have attracted a great deal of theoretical attention.

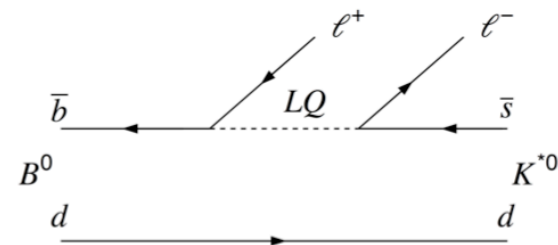


New particles at or above 1 TeV were proposed, to induce NU lepton interactions

- It has been pointed out that any departure from LU is necessarily associated with LF violation, and no known symmetry principle can protect one in the absence of the other, see [S.L. Glashow, D. Guadagnoli, K. Lane, PRL 114, 091801 \(2015\)](#)

# LF VIOLATION IN $B^0_{(s)} \rightarrow e^+ \mu^-$

- The decays  $B^0 \rightarrow e^+ \mu^-$  and  $B^0_s \rightarrow e^+ \mu^-$  are forbidden in the SM, but allowed in several NP scenarios:
  - ❑ Heavy single Dirac neutrinos [Ilakovic, PRD 62 \(2000\), 036010](#)
  - ❑ SUSY models [R. A. Diaz et al., EPJ C41 \(2005\), 305.](#)
  - ❑ The Pati-Salam model, postulating new gauge bosons that carry both color and lepton quantum numbers [J. C. Pati and A. Salam, PRD 10 \(1974\), 275.](#)
  - ❑ Littlest Higgs model with T-Parity (LHT) [M. Blanke et al., JHEP 05 \(2007\)](#)
- Current mass limits from CMS exist on leptoquark models that involve quark-lepton couplings within the same generation  
[The CMS collaboration, arXiv: 1703.03995](#)
- Limits on the above LFV decays are close to the level of providing complementary cross-checks of the observed LNU in the weak anomalies, particularly in the channels  $B \rightarrow K \mu e$ ,  $K \mu \tau$  and  $B_s \rightarrow \mu e$ ,  $\mu \tau$   
[S.L. Glashow, D. Guadagnoli, K. Lane, PRL 114, 091801 \(2015\)](#)

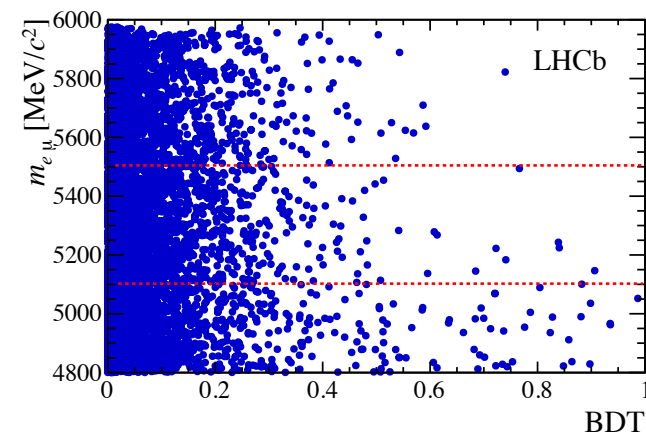
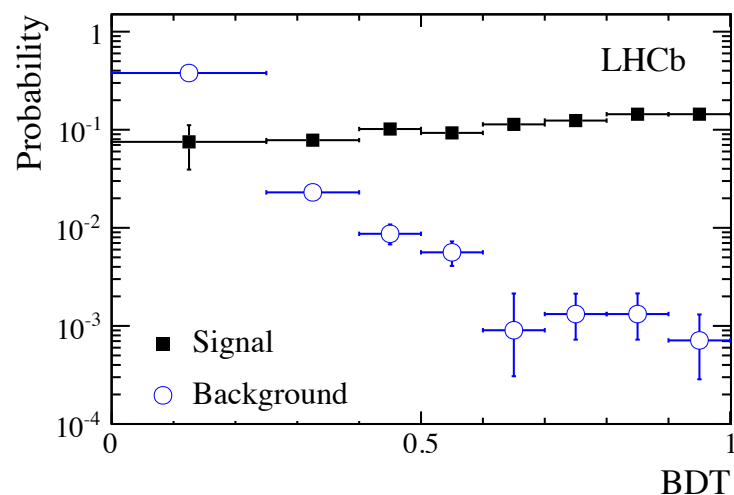


# LHCb ANALYSIS $B^0_{(s)} \rightarrow e^+ \mu^-$

■ The LHCb analysis is based on exclusive  $B^0_{(s)} \rightarrow h^+ h'^-$  triggers ( $h^{(\prime)} = K, \pi$ ). The signal has a well identified electron and muon, with a displaced vertex from the pp collision, in a mass interval  $[5.1, 5.5]$   $\text{GeV}/c^2$ . A multivariate classifier (BDT) is defined to perform optimal S/B separation

■  $B^+_c \rightarrow J/\psi (\mu^+ \mu^-) e^+ \nu_e$  and  $B^+_c \rightarrow J/\psi (e^+ e^-) \mu^+ \nu_\mu$  are dominant sources of background for  $\text{BDT} > 0.5$ , having an  $e\mu$  mass distribution compatible with an exponential in the range  $[4.9, 5.9]$   $\text{GeV}/c^2$ . Their contribution is assessed by fitting the mass spectrum at the signal sidebands.

Phys. Rev. Lett. **111**, 141801 (2013)



# LHCb RESULTS ON $B^0_{(s)} \rightarrow e^+ \mu^-$

- The number of candidates in the high BDT agrees with the expected backgrounds. For each BF hypothesis, the CL is computed ( $CL_s$ ).

- The obtained 95% CL limits are the most stringent to date (only  $\sim 1/3$  of total Run1 luminosity used:  $1 \text{ fb}^{-1}$ )

$$\mathcal{B}(B_s^0 \rightarrow e^\pm \mu^\mp) < 1.4 \times 10^{-8}$$

$$\mathcal{B}(B^0 \rightarrow e^\pm \mu^\mp) < 3.7 \times 10^{-9}$$

Pati-Salam leptoquark lower mass limits:

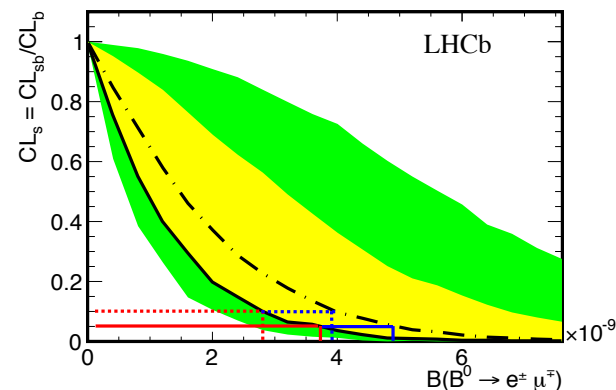
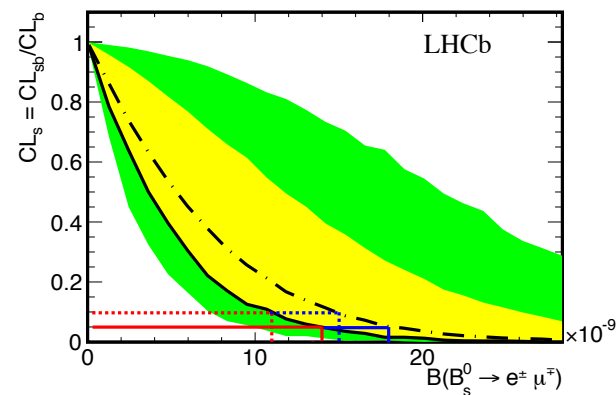
$$M_{LQ}(B_s^0 \rightarrow e^\pm \mu^\mp) > 101 \text{ TeV}/c^2$$

$$M_{LQ}(B^0 \rightarrow e^\pm \mu^\mp) > 126 \text{ TeV}/c^2$$

better by a factor of two than previous limits

- LHCb is working on updating the above LFV results to full Run2 luminosity, and further extend it to searches  $B \rightarrow K e^+ \mu^-$  and  $B \rightarrow K e^+ \tau^-$

Phys. Rev. Lett. **111**, 141801 (2013)

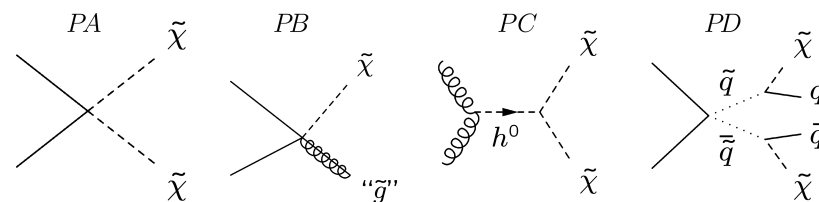


- Lepton number violation is found in the context of minimal super-gravity SUSY (mSUGRA) with R-parity violation (RPV), where neutralinos can decay into a muon and two quarks ( $\tilde{\chi}_1 \rightarrow \mu^- q_u \bar{q}_d$ ) [B. Allanach, A. Dedes, H. Dreiner, Phys. Rev. D69 \(2004\) 1150002](#)

- A subset of SUSY models features massive *long-lived* particles with measurable flight distance

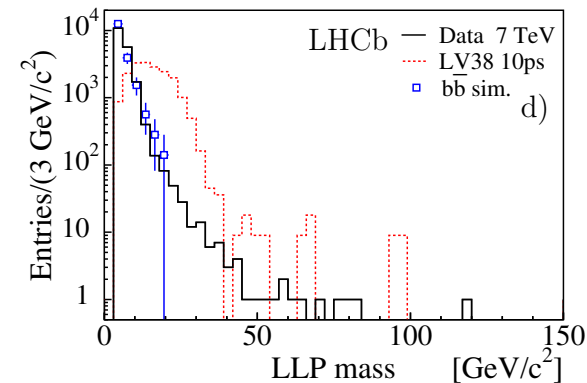
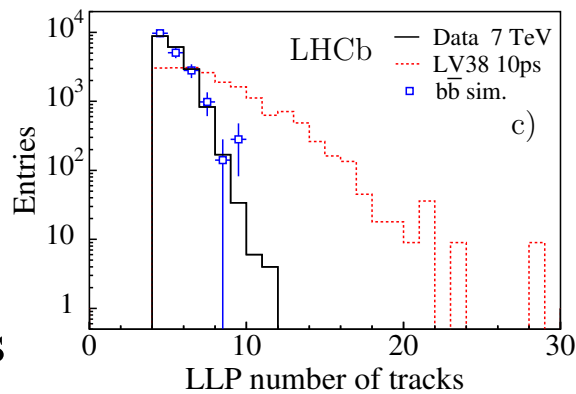
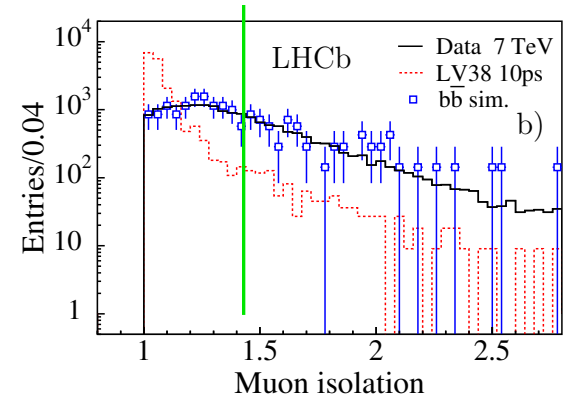
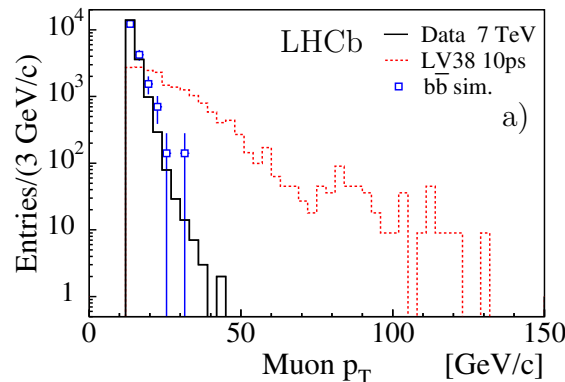
[P. Graham et al., JHEP 07 \(2012\) 149](#)

[M. Strassler, K. Zurek, Phys. Lett. B661 \(2008\) 263](#)



- LHCb probes the forward rapidity region at the LHC, and triggers on particles with low  $p_T$ , which allows to explore *relatively small long-lived particle masses*:  $20 < m_{\text{LLP}} < 80$  GeV. Precision vertexing (flight distances up to 40 cm), enables the search for particle lifetimes in the range  $1 \text{ ps} < \tau_{\text{LLP}} < 100 \text{ ps}$ .
- Four processes were considered by LHCb that include the LNV decay  $\tilde{\chi}_1 \rightarrow \mu^- q_u \bar{q}_d$  in particular the Higgs final states  $H^0 \rightarrow \tilde{\chi}_1 \tilde{\chi}_1$  in the mass range  $50 < m_H < 130$  GeV [Eur. Phys. J. C \(2017\) 77: 224 \[arXiv:1612.00945\]](#)

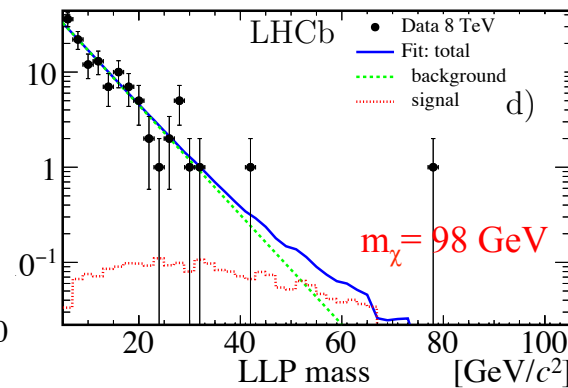
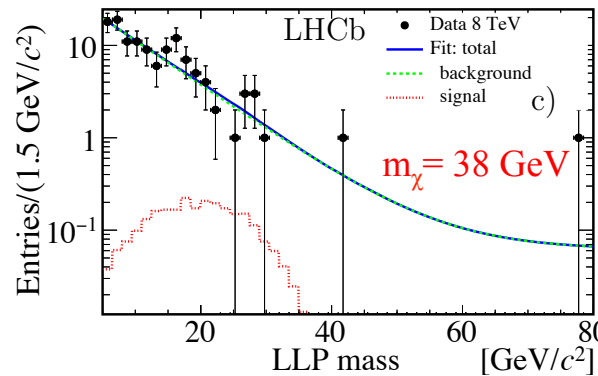
- The signature is a high  $p_T$  muon (12 GeV/c) associated with a displaced vertex with  $N \geq 4$  ( $R_{xy} > 550 \mu\text{m}$ )
- A multi-variate classifier (MLP) is used to further purify the sample against heavy quark ( $b\bar{b}, t\bar{t}, c\bar{c}$ ) and W/Z backgrounds.
- A muon isolation cut (1.4) is used to model the background (data-driven), since no simulated  $b\bar{b}$  events survive the MLP filter



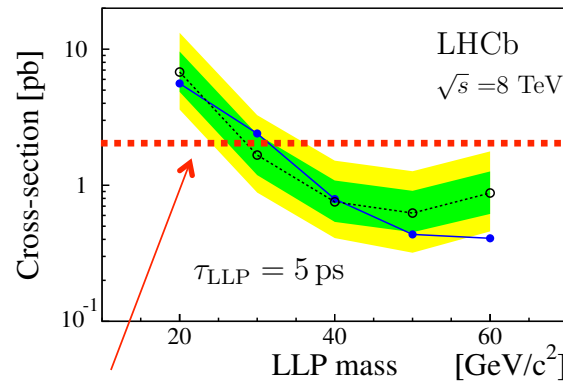
Eur. Phys. J. C (2017) 77: 224 [arXiv:1612.00945]

Eur. Phys. J. C (2017) 77: 224 [arXiv:1612.00945]

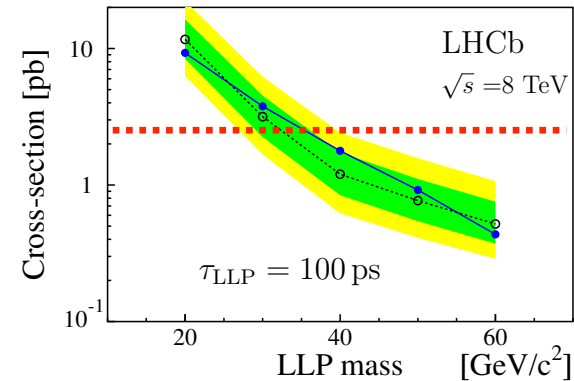
- The signal yield is obtained from a ML fit to the mass distribution  $m_{\text{LLP}}$



- Upper limits on  $\sigma \times \text{BR}$  are obtained for a Higgs boson  $m_H = 125 \text{ GeV}/c^2$  with LLP lifetime ranging from 5 ps to 100 ps



BR(H)=10%



- When compared to the SM prediction for Higgs production of 19 pb (8 TeV), a 10%  $\mathcal{B}(H^0 \rightarrow \tilde{\chi}_1 \tilde{\chi}_1)$  into long-lived neutralinos with LNV decay (inspired by RPV SUSY), can be excluded at 95% CL for  $30 \leq m_{\text{LLP}} \leq 60 \text{ GeV}/c^2$

# RECASTING LHCb RESULT TO STERILE NEUTRINO LIMITS

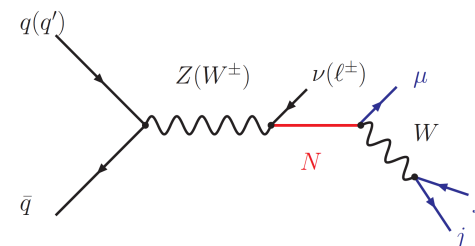
- The above LHCb results (Run1) have been recast to derive estimates for the constraints on sterile neutrino parameters  
*Eur. Phys. J. C (2017) 77: 224*

S. Antusch, E. Cazzato, O. Fischer (2017)  
arXiv: 1706.05990

- Benchmark model used

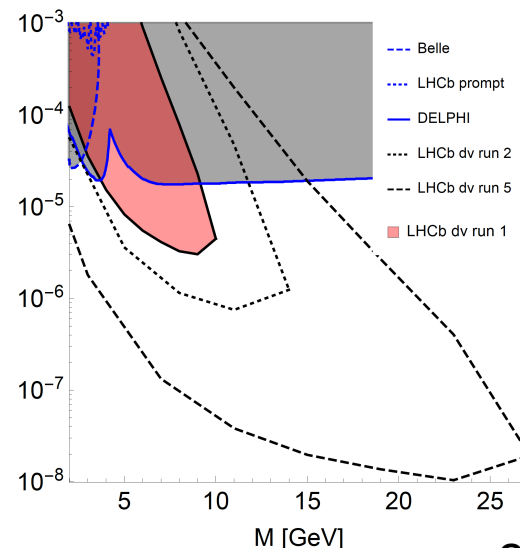
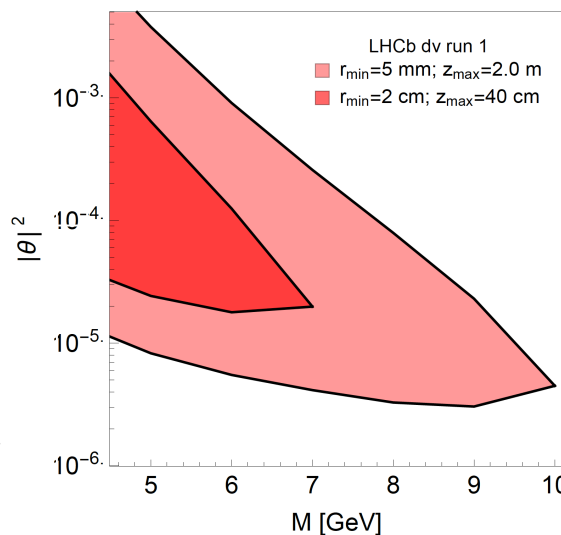
S. Antusch, O. Fischer, JHEP 1505 (2015) 053

- For  $N$  masses below  $m_W$  and small *active-sterile neutrino mixing*  $|\theta|^2$  the lifetime of the heavy neutrino can be long enough such that it decays into a displaced secondary vertex from the interaction point



- Estimates indicate that for  $m_N \sim 9$  GeV  $|\theta|^2$  is constrained down to  $\sim 3 \times 10^{-6}$  (95% CL)

- The authors suggest that for  $4.5 < m_N < 10$  GeV the currently analysed LHCb data provides the strongest existing exclusion limit for  $|\theta|^2$



# SUMMARY

- ❑ Leading LHCb results were presented on lepton flavor violation in  $c$ -,  $\tau$ -, and  $b$ -decays, typically reaching the  $10^{-8}$  level. These results set important constraints on several new physics models, and begin to provide complementary information to the lepton non-universality hints observed in weak anomalies.
- ❑ Searches for GeV-scale 4<sup>th</sup> generation sterile Majorana neutrinos by the LHCb experiment were reported, providing new mass-versus-mixing limits. Some prospects for LHC Run3 were outlined.
- ❑ Recent LHCb results were discussed searching for lepton number violating decays of long-lived particles (LLP), in the mass range between 20 and 60 GeV. In particular, a 10% branching fraction of a Higgs-like boson of mass 125 GeV decaying into two such LLP's is excluded at 95% CL, within the RPV SUSY framework.



# THANK YOU